

Clinical evaluation of the centre of resistance of the upper incisors during retraction

Tamer Türk*, Selma Elekdag-Türk* and Müfide Dinçer**

*Department of Orthodontics, University of Ondokuz Mayıs, Samsun and **Department of Orthodontics, University of Gazi, Ankara, Turkey

SUMMARY The aim of this study was to evaluate the movement of anterior teeth during retraction with a force applied through the assumed centre of resistance (CR_e).

Twenty-two subjects with a Class I or II malocclusion were included. Each subject had the two upper first premolars extracted, resulting in a symmetrical extraction space of at least 3 mm between the upper laterals and canines. The force was applied through the assumed CR_e, located 9 mm gingival to the lateral tooth bracket. To examine the type of anterior tooth movement, 10 parameters were measured. A Wilcoxon test was used to determine the differences between pre- and post-retraction values, and a Mann–Whitney *U*-test to determine the mean differences between groups.

In spite of the force application through the CR_e, tipping of the anterior teeth was observed in 19 subjects and parallel movement in three patients. Consequently, the subjects were divided into two groups according to the location of the centre of rotation (CR_o). In group 1 (nine cases), the CR_o was located coronal to the root apex, and in group 2 (13 cases), apical to the root apex.

Both groups showed a significant decrease in inclination ($P < 0.01$) and posterior crown movement ($P < 0.01$ for group 1 and $P < 0.001$ for group 2) of the anterior teeth. A significant posterior movement of the root apex was observed in group 2 ($P < 0.001$). Significant differences were found between the groups for anterior tooth inclination ($P < 0.05$) and root apex movement ($P < 0.001$). The reasons for these differences could not be conclusively determined.

Even though experimental studies provide information regarding CR_e location, factors such as bone support, root morphology and incisor inclination should be taken into consideration. The observation of tooth movement occurring during treatment and changes in treatment mechanics would be helpful in obtaining desired tooth movement.

Introduction

Anterior tooth retraction represents a fundamental phase of fixed orthodontic appliance treatment. Three-dimensional control of anterior tooth movement and correct positioning of teeth are important for function, aesthetics and stability (Gjessing, 1994).

Different mechanics have been used for the retraction of incisors (Cadman, 1975; Burstone, 1982; Root, 1985; Gjessing, 1992, 1994).

Retraction forces are applied at the level of the brackets in most techniques. In order to prevent tipping and to obtain parallel tooth movement, a moment in the opposite direction should be applied that has the same magnitude as the moment of the retractive force (Smith and Burstone, 1984; Marcotte, 1990; Gjessing, 1994).

Another way to obtain parallel movement is to pass the line of action of force through the centre of resistance (CR_e). For this purpose, the force is applied at the edge of a lever arm extended from the bracket to the gingiva. In this situation, the line of action of force passing through the CR_e causes parallel movement, even though the lever arm is attached to the bracket (Smith and Burstone, 1984).

To control tooth movement, the balance between the line of action of force and the CR_e should be determined

correctly (Smith and Burstone, 1984). The critical point in determining this balance is defining the location of the CR_e (Gjessing, 1994).

In vitro studies have been carried out with different materials and methods to determine the position of the CR_e of anterior teeth with retractive forces (Vanden Bulcke *et al.*, 1987; Pedersen *et al.*, 1991a; Matsui *et al.*, 2000). Vanden Bulcke *et al.* (1987), using the laser reflection technique on dry human skulls, observed that the CR_e of the upper incisors was located 5 mm apical to the interproximal bone of the central incisors.

The localization of the CR_e of four anterior teeth was investigated on human autopsy material with retractive forces (Pedersen *et al.*, 1991a). In that study, the CR_e of the upper incisors was located 5 mm apical to the bracket level, which was positioned 4 mm from the incisal edge.

The localization of the CR_e of the upper incisors has been investigated on photoelastic models (Matsui *et al.*, 2000). Those authors reported that the CR_e of the upper incisors was located 6 mm apical to the labial alveolar crest of the central incisor.

The studies by Gjessing (1992, 1994), introducing the PG retraction spring for maxillary incisors, stated that the CR_e of the upper incisors was located 7 mm

distal and 9–10 mm gingival to the centre of the lateral bracket. In those studies, the PG retraction spring was calibrated according to the localization of the CRe obtained from human autopsy material.

Vanden Bulcke *et al.* (1987), Pedersen *et al.* (1991a), and Matsui *et al.* (2000) only investigated the initial tooth movement and the instantaneous CRe of anterior teeth, which may help to forecast the longitudinal tooth movement following force application. However, the materials used in those studies had no capacity to react biologically to force application; longitudinal tooth movement during retraction cannot be investigated *in vitro*.

The aim of this study was to evaluate anterior tooth movement during retraction with a force applied through the assumed CRe.

Subjects and method

Twenty-two subjects (20 females, two males; average chronological age 18 years 7 months) with a Class I or II malocclusion and average overjet values of 6.87 mm were selected for the retraction of four maxillary incisors. All patients were undergoing orthodontic treatment with 0.018 inch standard edgewise mechanics, including extraction of the upper first premolars. At the beginning of incisor retraction, all had completed retraction of the maxillary canines, and had a symmetrical space of at least 3 mm between the upper laterals and canines.

To form the anchorage units, 0.018 × 0.025 inch stainless steel wires were ligated to the canine, second premolar and molar. The buccal segments were joined with a transpalatal bar. The four incisors were consolidated with 0.018 × 0.025 inch stainless steel wires to form the anterior segment. In the buccal and anterior segments, the archwire was bent to form lever arms. These lever arms were used to direct the force through the CRe of the anterior teeth, which was located 9 mm gingival from the lateral tooth bracket. The retraction force (150 g/per side) was applied between the anterior and posterior lever arms.

In order to biometrically evaluate movement of the anterior teeth, cephalometric films were taken at the beginning and end of retraction. Local superimpositions of these pre- and post-retraction lateral cephalometric films were carried out with reference to a point in the palatal cortex of the maxilla by one author (TT). A coordinate system was set up on the pre-retraction lateral cephalometric films: the line through Ptm, pterygomaxillary point and perpendicular to the ANS–PNS plane represented the *y*-axis (VerL) and the ANS–PNS plane, the *x*-axis (HorL). These axes served as references for the local superimpositions during angular and linear measurements in the horizontal and vertical directions. Ten parameters were measured to examine the type of anterior tooth movement (Figure 1).

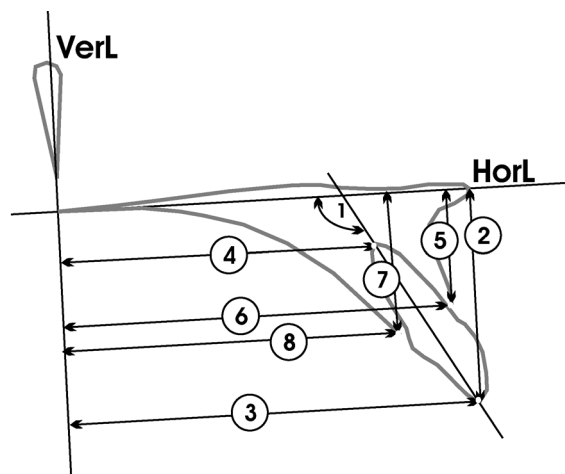


Figure 1 Linear and angular points measured on the pre- and post-retraction lateral cephalometric films. 1, U1/HorL (degrees): the angle between the long axis of the upper central incisor and the horizontal line; 2, U1cr–HorL (mm): the distance between the incisal edge of the upper central incisor and the horizontal line; 3, U1cr–VerL (mm): the distance between the incisal edge of the upper central incisor and the vertical line; 4, U1ra–VerL (mm): the distance between the root apex of the upper central incisor and the vertical line; 5, Pr–HorL (mm): the distance between prosthion point and the horizontal line; 6, Pr–VerL (mm): the distance between prosthion point and the vertical line; 7, PPr–HorL (mm): the distance between posterior prosthion point and the horizontal line; 8, PPr–VerL (mm): the distance between posterior prosthion point and the vertical line; 9, root length (mm): the distance between the alveolar bone crest and the root apex; 10, overjet (mm): the horizontal overlap between the incisal edges of the upper and lower incisors.

To determine the type of tooth movement, the centre of rotation (CRO) was calculated. The point of intersection of the pre- and post-treatment long axes of the central incisor was used for the determination of the CRO. To measure the location of the CRO, the root apex was accepted as the zero point. A positive value indicated a location of the CRO apical to this point, and a negative value a location coronal to this point.

The subjects were divided into two groups according to the location of the CRO. In group 1 (nine patients), the CRO was located coronal to the root apex, and in group 2 (13 patients), apical to the root apex. A Wilcoxon test was used to determine the differences between pre- and post-retraction values, and a Mann–Whitney *U*-test to determine the mean differences between the groups.

The size of the method error for the measurements was calculated using Dahlberg's formula (1940): method error = $\sqrt{\sum d^2/2n}$, where *d* is the difference between two measurements of a pair and *n* is the number of double measurements. The method error did not exceed 0.30 mm for any variable investigated.

Table 1 Comparison of the differences between pre- and post-retraction values ($n = 22$).

Parameters	Pre-retraction			Post-retraction			<i>P</i>
	Mean	SE	SD	Mean	SE	SD	
1. U1/HorL (degrees)	112.7	1.7	7.8	106.6	1.6	7.3	0.000***
2. U1cr-HorL (mm)	31.2	0.7	3.5	31.5	0.7	3.4	0.200
3. U1cr-VerL (mm)	55.2	0.9	4.5	52.9	0.9	4.4	0.000***
4. U1ra-VerL (mm)	46.9	0.7	3.2	46.1	0.6	3.0	0.001***
5. Pr-HorL (mm)	18.1	0.7	3.4	18.3	0.7	3.2	0.451
6. Pr-VerL (mm)	53.6	0.7	3.5	52.8	0.7	3.5	0.000***
7. PPr-HorL (mm)	20.7	0.7	3.1	20.5	0.7	3.1	0.225
8. PPr-VerL (mm)	46.5	0.8	3.6	45.6	0.7	3.5	0.000***
9. Root length (mm)	13.1	0.3	1.6	-	-	-	-
10. Overjet (mm)	6.9	0.4	1.8	3.8	0.2	0.9	0.000***

SE, standard error of the mean; SD, standard deviation.

Table 2 The localization of the centre of rotation (CRo) with respect to the root apex in all subjects ($n = 22$). Negative values indicate the CRo lying coronal to the root apex.

Number of cases	Localization of CRo (mm)	Number of cases	Localization of CRo (mm)
1	3.5	1	-1.5
2	20.0	2	-2.5
3	∞	3	-5.0
4	∞	4	-4.0
5	4.0	5	-4.0
6	7.0	6	-3.0
7	∞	7	-1.5
8	4.5	8	-1.0
9	12.5	9	-3.0
10	6.5		
11	4.0		
12	2.0		
13	4.0		

Results

The statistical values of the pre- and post-retraction measurements, as well as the statistical differences, are given in Table 1. U1cr-VerL, U1ra-VerL, Pr-VerL and PPr-VerL dimensions and U1/HorL angle demonstrated a significant decrease ($P < 0.001$).

In nine subjects, the CRo was located coronal to the root apex (group 1), and in 13 subjects apical to the root apex (group 2). In three patients, the CRo was infinite, i.e. the upper incisors demonstrated parallel movement (Table 2). For both groups, descriptive statistical values of pre- and post-retraction measurements are given in Table 3. The changes that occurred during retraction and the comparison of these changes within each group and between the groups are shown in Table 4 and Figure 2.

In group 1 there was a significant decrease in U1/HorL angle and U1cr-VerL distance ($P < 0.01$), and Pr-VerL and PPr-VerL distances ($P < 0.05$). U1cr-HorL distance

Table 3 Pre- and post-retraction descriptive values for both groups.

Parameters	Group 1 ($n = 9$)						Group 2 ($n = 13$)					
	Pre-retraction			Post-retraction			Pre-retraction			Post-retraction		
	Mean	SE	SD	Mean	SE	SD	Mean	SE	SD	Mean	SE	SD
1. U1/HorL (degrees)	115.3	2.2	6.6	107.2	1.8	5.3	110.9	2.3	8.2	106.2	2.4	8.5
2. U1cr-HorL(mm)	30.7	1.2	3.5	31.6	1.1	3.5	31.6	1.0	3.6	31.4	1.0	3.5
3. U1cr-VerL (mm)	55.3	1.3	3.9	52.3	1.4	4.1	55.1	1.4	4.9	51.7	1.3	4.7
4. U1ra-VerL (mm)	46.1	1.2	3.6	45.9	1.2	3.7	47.5	0.8	2.8	46.2	0.7	2.6
5. Pr-HorL (mm)	17.6	1.2	3.7	17.8	1.1	3.4	18.5	0.9	3.3	18.6	0.9	3.1
6. Pr-VerL (mm)	53.4	1.3	3.9	52.6	1.2	3.7	53.8	0.9	3.4	52.9	0.9	3.4
7. PPr-HorL (mm)	20.7	1.2	3.6	20.5	1.1	3.3	20.8	0.8	2.8	20.5	0.8	3.1
8. PPr-VerL (mm)	46.6	1.3	3.9	45.9	1.3	3.8	46.5	0.9	3.5	45.4	0.9	3.4
9. Root length (mm)	13.2	0.5	1.5	-	-	-	12.9	0.5	1.7	-	-	-

SE, standard error of the mean; SD, standard deviation.

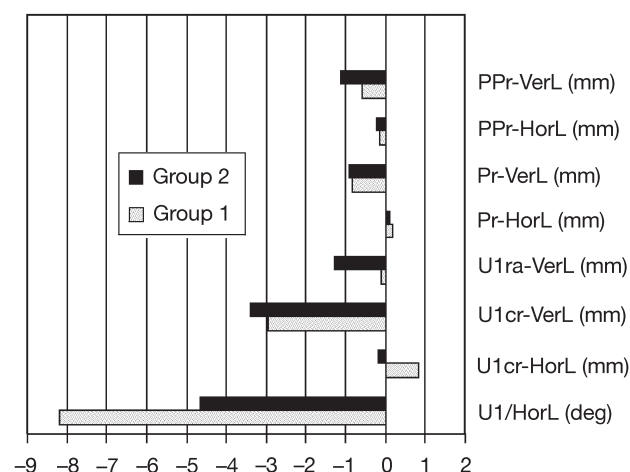
Group 1, centre of rotation located coronal to the root apex; group 2, centre of rotation located apical to the root apex.

Table 4 The mean changes during the retraction period and comparisons between the groups.

Parameters	Group 1 (n = 9)				Group 2 (n = 13)				P
	D	SE	SD	P	D	SE	SD	P	
1. U1/HorL (degrees)	-8.1	1.1	3.2	0.008**	-4.7	1.0	3.5	0.003**	0.025*
2. U1cr-HorL (mm)	0.9	0.1	0.4	0.007**	-0.2	0.2	0.7	0.319	0.001***
3. U1cr-VerL (mm)	-3.0	0.3	1.0	0.007**	-3.4	0.6	2.7	0.001***	1.000
4. U1ra-VerL (mm)	-0.2	0.1	0.2	0.157	-1.3	0.1	0.5	0.001***	0.000***
5. Pr-HorL (mm)	0.2	0.3	0.9	0.550	0.1	0.2	0.7	0.719	0.744
6. Pr-VerL (mm)	-0.8	0.2	0.6	0.017*	-0.9	0.1	0.4	0.002**	0.845
7. PPr-HorL (mm)	-0.2	0.3	0.8	0.546	-0.3	0.2	0.8	0.304	0.845
8. PPr-VerL (mm)	-0.7	0.2	0.6	0.026*	-1.1	0.2	0.8	0.004**	0.082

D, mean difference; SE, standard error of the mean; SD, standard deviation.

Group 1, centre of rotation located coronal to the root apex; group 2, centre of rotation located apical to the root apex.

**Figure 2** Changes (in mm) observed during the retraction period in the two groups.

increased significantly ($P < 0.01$). In group 2 there was a significant decrease in U1cr-VerL and U1ra-VerL distances ($P < 0.001$), while Pr-VerL and PPr-VerL distances demonstrated a significant decrease ($P < 0.01$). U1/HorL angle decreased a statistically significant amount ($P < 0.01$).

The decreases relating to U1/HorL angle and U1ra-VerL distance were found to be statistically significant between the groups ($P < 0.05$ and $P < 0.001$, respectively). The changes observed in U1cr-HorL distance showed a significant difference between the groups ($P < 0.001$).

Discussion

The first study of CRE determination of upper incisors with a retraction force was carried out on dry human skulls (Vanden Bulcke *et al.*, 1987). The use of skulls has some advantages, such as evaluation of initial tooth movement and variable force systems within the same skeletal structure without any alteration of the

anatomical geometry. However, some limitations, such as the simulation of biological structures, i.e. periodontal ligament (PDL), were encountered in that study. Human autopsy material has also been used for the determination of the CRE of anterior teeth to overcome the limitation arising from simulating the biological structure (Pedersen *et al.*, 1991a). The results obtained from human autopsy material were found to be close to *in vivo* measurements, when continuous and low forces were applied (Pedersen *et al.*, 1991b). Photoelastic models were subsequently used for the localization of the CRE of upper incisors (Matsui *et al.*, 2000). With this method, the observation of stress distribution around the teeth provided a more accurate localization of the CRE. However, the results of these investigations cannot be extrapolated to clinical studies (Pedersen *et al.*, 1991a, b; Matsui *et al.*, 2000).

Pedersen *et al.* (1991a) stated that the CRE of the upper incisors is located 5 mm apical to the bracket level. On the other hand, Gjessing (1992, 1994) reported that the CRE of the upper incisors is located 9–10 mm gingival to the centre of the lateral bracket. In the present study, the line of action of force passed through the assumed CRE, 9 mm apical from the lateral bracket level.

The inclination of the upper incisors demonstrated an average decrease of 6.1 degrees. The upper incisor crown moved 2.3 mm posteriorly, whereas the root apex moved 0.8 mm (Table 1). Although the line of action of force passed through the assumed CRE, two different types of tipping movement were observed. The CRO was located coronal to the root apex in nine subjects (group 1, uncontrolled tipping) and apical to the root apex in 13 patients (group 2, controlled tipping) (Table 2). For this reason, the subjects were divided into two groups according to the location of the CRO and compared according to the type of tooth movement and the factors affecting tooth movement.

The upper incisors tipped posteriorly 8.1 and 4.7 degrees in groups 1 and 2, respectively (Table 4). This

difference was found to be statistically significant, and was consistent with less posterior root apex movement in group 1. These results show that in all subjects (except three), the line of action of force was located coronal to the assumed CRe. Thus, controlled and uncontrolled tipping was inevitable. The observation of parallel tooth movement, as well as different types of tipping movement, suggests that individual differences should also be considered.

The differences in bone support, root morphology and tooth inclination can change the location of the CRe (Kusy and Tulloch, 1986; Melsen *et al.*, 1990; Tanne *et al.*, 1991; Pedersen *et al.*, 1991b). The increase in root length and the decrease in alveolar bone height cause an apical movement of the CRe (Kusy and Tulloch, 1986; Tanne *et al.*, 1991; Pedersen *et al.*, 1991b). The CRe moves 1.3 mm to the apical with a root length increase of 50 per cent and the CRe moves 4 mm to the apical with an alveolar bone height decrease of 50 per cent (Tanne *et al.*, 1991).

In the present investigation, the root length of the central incisor did not show a statistically significant difference between groups and did not affect the location of the CRe.

In the current study, the sagittal and vertical movements of anterior and posterior prosthion points were measured to observe the movements of the anterior and posterior alveolar bone located between the two central incisors. The anterior (0.8 mm in group 1, 0.9 mm in group 2) and posterior (0.7 mm in group 1, 1.1 mm in group 2) prosthion points moved posteriorly and followed the tooth movement (Table 4). In both groups, these movements were found to be statistically significant. Vertical movement measurements of these points demonstrated that anterior prosthion point moved downwards (0.12 mm in group 1, 0.1 mm in group 2) due to apposition, and posterior prosthion point moved upwards (0.2 mm in group 1, 0.3 mm in group 2) due to resorption (Table 4). These minimal changes did not have any effect on alveolar bone support and thus the location of the CRe was not clinically affected.

Melsen *et al.* (1990), in their study investigating the vertical force effects of T-loop springs, stated that the relationship between the point of force application and the CRe changed due to the root length and axial inclination of the teeth. The relationship between the CRe of six upper anterior teeth and the point of force application (canine bracket) in the sagittal direction was investigated. They found that in subjects with proclination of the anterior teeth, the point of force application is located anterior to the CRe and with retroinclination of the anterior teeth, posterior to the CRe. The same relationship between the CRe and the point of force application (bracket level) may be applied in the vertical direction. In subjects with proclination of the anterior teeth, the point of force application is located

close to the CRe and with retroinclination of the anterior teeth, distant to the CRe. Although in group 1 the inclination of the anterior teeth was more than in group 2 (Table 3), the difference was not statistically significant. The difference in axial inclination, observed between the two groups, did not have any effect on the relationship between the CRe and the point of force application.

No differences in root morphology, alveolar bone support and axial inclination were observed between the groups, which raises questions concerning the location of the CRe in other studies. The vertical relationships between the locations of the CRe are shown in Figure 3. The locations of the assumed CRe ranged between 5 and 15 mm in relation to the bracket level when the bracket level and mesial contact of the central incisors were superimposed on the *x*- and *y*-axes. The CRe in the present study was located nearly at the same position as that reported by Vanden Bulcke *et al.* (1987) and between the CRe found by Pedersen *et al.* (1991a) and Matsui *et al.* (2000).

Whether the materials used (dry human skull, human autopsy material and photoelastic material) have an effect on the wide range of CRe locations remains a question to be answered. Vanden Bulcke *et al.* (1987) stated that structural and spatial relationships of the dentofacial components are different among subjects and this difference may affect the CRe localization. The difference in tooth movement of two dry human skulls was explained by the width of the artificial PDL and bone elasticity. It is stated that bone-root anatomy and PDL morphology might affect the location of the CRe *in vivo* (Vanden Bulcke *et al.* 1987).

Reference points used to determine CRe localization vary. Pedersen *et al.* (1991a) used the bracket position, Matsui *et al.* (2000) the labial alveolar crest of the central incisor and Vanden Bulcke *et al.* (1987) the interproximal bone level. The variation in reference points and the difficulty of clinical observation of some of these

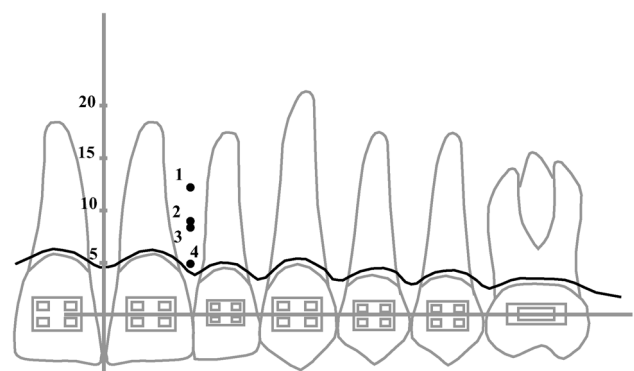


Figure 3 Vertical relationship of the centre of resistance localization determined by (1) Matsui *et al.* (2000), (2) Gjessing (1992, 1994), (3) Vanden Bulcke *et al.* (1987), (4) Pedersen *et al.* (1991a).

reference points might lead to problems for the accurate determination of the CRe.

Conclusions

The present results provide guidance and indicate the general trends of CRe location. The determination of the CRe location for each subject with consideration of alveolar bone support, root morphology and tooth inclination would be more reliable. The examination of the relationship between the individual CRe and the line of action of force, the observation of tooth movement occurring during treatment and changes in treatment mechanics would be helpful in obtaining desired tooth movement.

Address for correspondence

Tamer Türk
Department of Orthodontics
Faculty of Dentistry
University of Ondokuz Mayıs
55139 Samsun
Turkey
Email: turkset@superonline.com

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